FINAL REPORT

DEVELOPMENT OF PERSONAL PROTECTIVE EQUIPMENT FOR DECONTAMINATION AND DECOMMISSIONING

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Florida International University Collaborator:

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Prepared for:

U.S. Department of Energy
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Office of Science and Technology

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DISCLAIMER

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LIST OF ACRONYMS

AmSL	Allowable minimum Safety Limits
D&D	Deactivation and Decommissioning
DOE	Department of Energy
ECG	Electro Cardio Gram
° F	Degrees Fahrenheit
PCFA	Pre-Chilled or Forced-Air System
PCS	Personal Cooling Systems
PICS	Personal Ice Cooling System
PME	Personal Monitoring Equipment
PMH	Personal Monitoring Harness
PPE	Personal Protective Equipment
PTP	Project Technical Plan
PVS	Passive Vest System
SCAMP	Super Critical Air Mobility Pack
Tty	Tympanic Temperature
UFCS	Umbilical Fluid-Chilled System

NOMENCLATURE

Biotelemetry: Technology that combines radio transmitters with medical monitoring equipment.

EXECUTIVE SUMMARY

The purpose of this one-year investigation is to perform a technology integration/search, thereby ensuring that the safest and most cost-effective options are developed and subsequently used during the deactivation and decommissioning (D&D) of U.S. Department of Energy Environmental Management (DOE-EM) sites. Issues of worker health and safety are the main concern, followed by cost. Two lines of action were explored: innovative Personal Cooling Systems (PCS) and Personal Monitoring Equipment (PME). PME refers to sensors affixed to the worker that warn of an approaching heat stress condition, thereby preventing it.

Three types of cooling systems were investigated: Pre-Chilled or Forced-Air System (PCFA), Umbilical Fluid-Chilled System (UFCS), and Passive Vest System (PVS). Of these, the UFCS leads the way. The PVS or Gel pack vest lagged due to a limited cooling duration. And the PCFA or chilled liquid air supply was cumbersome and required an expensive and complex recharge system. The UFCS in the form of the Personal Ice Cooling System (PICS) performed exceptionally. The technology uses a chilled liquid circulating undergarment and a Personal Protective Equipment (PPE) external pump and ice reservoir. The system is moderately expensive, but the recharge is low-tech and inexpensive enough to offset the cost.

There are commercially available PME that can be augmented to meet the DOE's heat stress alleviation need. The technology is costly, in excess of $4,000 per unit. Workers easily ignore the alarm. The benefit to health & safety is indirect so can be overlooked. A PCS is a more justifiable expenditure.

1.0 INTRODUCTION

Many deactivation and decommissioning (D&D) activities require difficult tasks to be completed by workers in protective suits and respirators. Some suits essentially encapsulate the wearer's body, preventing the evaporation of perspiration, and thereby preventing the heat generated by the worker's activity from leaving the suit. As a result, the average worker cannot tolerate exposure to the hot and humid atmosphere for more than approximately 45 minutes, after which the worker has to cool down. The time required for donning and doffing a suit and respirator, along with the time required for decontamination, make for a workday that is, at best, less than 50% efficient and frequently only 25% efficient. The majority of personal protective equipment (PPE) is destined for the secondary waste stream and must be continuously replaced. Other items are laundered or cleaned, then reused. A substantial cost savings can be realized if the quantity of PPE sent for laundering and cleaning or entering the waste stream could be minimized by a system that itself is not cost-prohibitive. New PPE and systems are needed to improve performance and increase savings.

This is the first and last year of what was originally a two-year project. At the mid-year review, this project was redirected from the scope in the Project Technical Plan (PTP) submitted for Fiscal Year 98 (FY98). The three primary objectives for this project were 1) to perform a market assessment of commercially available and innovative PPE, 2) to conduct laboratory-scale tests of selected PPE against established performance-based criteria, and 3) to facilitate product integration/development. To facilitate this project, the Federal Energy Technology Center (FETC) sent a package of PPE related documents to FIU-HCET. In this package was a draft of a report titled *Personnel Protective Clothing Needs Within the DOE Weapons Complex* submitted by Energetics, Inc. A list of commercially available PPE vendors had already been compiled, and a product assessment had been done on a select few products. FETC and Florida International University's Hemispheric Center for Environmental Technology (FIU-HCET) decided that this project should take on a new focus.

The revised objectives are 1) to perform a review to determine if there are any innovative technologies that meet the defined PPE needs and 2) to perform a technology integration activity to monitor heat stress, contamination control, and other factors using existing PPE. This report explains how these goals were achieved.

2.0 PROJECT DESCRIPTION AND OBJECTIVES

TASK 1. IDENTIFICATION OF COMMERCIALLY AVAILABLE PPE AND VENDORS

After having started this task, the package with the Energetics report was received. The list complied by FIU-HCET was first presented as an appendix to the PPE monthly report. The complete list including those complied by Energetics is presented as an attachment to this report.

TASK 2. SURVEY OF MAJOR DOE OPERATION SITES

This task was sufficiently conducted by Energetics, so it was not redone by FIU-HCET. The following is a synopsis of the DOE's need and concerns for Improved Protective Clothing. The DOE uses two categories of PPE at its sites, disposable and non-disposable. Both types may result in heat stress for workers. Limited stay times alleviate the danger, but the job incurs an inefficiency of time and cost. The facilities follow all OSHA regulations whether the conditions are hazardous or non-hazardous when it comes to stay time in a heat stress environment. Compliance with regulations requires that workers take frequent breaks. What is needed is a portable cooling system that doesn't interfere with job performance and extends the useful job time. Instead of such a cooling system, a heat stress monitor device would be needed.

TASK 3. DESIGN OF LABORATORY-SCALE TESTING PROGRAM

The following general test plan was to be used to test select innovative cooling PPE and personal monitoring equipment.

FIU-HCET will field-simulate a D9&D activity with PPE to ascertain the effectiveness of cooling systems and monitoring equipment. The volunteer will perform a three-hour lifting and moving task to simulate the D&D activity. Tympanic temperature (Tty) and three skin temperatures (forehead, right arm, and right thigh) will be monitored every thirty minutes. The subject will be pre- and post-weighed on a digital scale to determine sweat loss. Biotelemetry will collect Electro Cardio Gram (ECG) information. The test engineer, to insure that the volunteer's heart rate falls within the normal limits for heavy exercise, will monitor the ECG readout. A 25% to 35% increase in sustained heart rate is acceptable. The subject will also provide a qualitative assessment of the cooling system performance. The test subject or test engineer can stop the test at any time.

The simulated activity will be comprised of a lightweight carrying activity over a short walking distance. No bending or lifting should be required to perform this part of the task. Next, the test subject will perform a hand tool manipulation job. Last, the participant will walk a lap around the test area. These activities will be repeated until thirty minutes have passed, then monitoring data will be collected. The task segment will be repeated until the three-hour test is completed. The test subject or test engineer can stop the test at any time.

The outcome of the mid-year review was a refocusing of the path forward. FIU-HCET optioned to perform a technology integration activity to monitor heat stress, contamination control, and other factors using existing PPE. For this task a volunteer would be outfitted with the prototype

Personal Monitoring Harness (PMH) and monitored as in the above-mentioned testing procedure. Three technologies would be tested: a commercially available heat stress monitoring system, a prototype single chip biotelemetry unit, and an FIU-HCET design improvement of a biotelemetry system.

TASK 4. LABORATORY-SCALE TESTING OF SELECTED PPE

The second option is a review to determine if there are any innovative technologies that meet the defined PPE. To accomplish this task, a number of Personal Cooling Systems (PCS) were evaluated.

The Kool N' Safe's KoolJacket Lite™ (KJL-4-65) was tested on site. Vendor information can be found in the Appendix. An FIU-HCET test engineer during a technology evaluation demonstration wore the garment. The 65°F Phase Change Material (PCM) or KoolPacks were allowed to chill in a container of ice and water for thirty minutes. The test engineer then donned the KoolJacket Lite™ and proceeded to do light handwork in the demonstration area. The test was conducted outdoors in a non-controlled environment; the temperature averaged 94°F ± 2°F with a 24% Humidity ± 3%. Under these conditions the test engineer reported that the jacket kept him cool for 30 minutes, after that the garment became uncomfortable to wear. Though the KoolPacks continued to supply cooling for an additional hour and a half, the condensation associated made the wearing burdensome. Such a PCS is categorized as an Ice/Gel/PCM Passive Vest System (PVS). Such systems are inexpensive and a comfortable temperature against the skin. They also provide a limited-duration of cooling and, since they are worn beneath PPE, require doffing to switch in new PCM packs. The recharge media can be a bucket of tap water and ice.

The next technology looked at was the Personal Ice Cooling System (PICS) by Delta Temax, Inc. PICS was tested at Fernald. This technology uses tap water and ice as a coolant. The water circulates through tubing incorporated into a full-body undergarment. An external ice bottle dissipates the heat collected by the cooling water. The PICS is an Umbilical Fluid-Chilled System (UFCS). The undergarments of such systems are not anti-contamination clothing, so they can be washed and reused and don't enter the secondary waste stream. UFCS provide long-duration cooling that is limited only by battery life and ice supply. However, these systems tend to be more expensive and, if condensation is allowed to form, the cooling efficiency and comfort suffer.

The last system reviewed was the Advanced Worker Protection System (AWPS) of Oceaneering Space Systems. The AWPS was demonstrated at Kansas State University. This system is a combination UFCS and a Pre-Chilled or Forced-Air System (PCFA). The body cooling is accomplished the same as the PICS, except the heat transferred from the body and then to the liquid is then transferred to a super-cooled air supply worn in a backpack. Then the warmed air passes to the full-face supplied air respirator. This system has the same general benefits and limitations as the PICS. The primary difference between them is that PICS uses ordinary tap water frozen in a freezer for ice. The AWPS requires a liquid nitrogen supply and a complex and expensive compressed air charging system. Another such system is the Super Critical Air Mobility Pack (SCAMP) by Aerospace Design and Development.

TASK 5. GENERATE FINAL REPORT AND DISTRIBUTE

This report represents completion of this task.

TASK 6. PRODUCT INTEGRATION AND/OR DEVELOPMENT

Biotelemetry describes a technology that monitors life processes (i.e., heart rate, breathing, or activity) and transmits this data to a remote collection site. Common uses of this technology are the tagging and release of animals in the wild or the monitoring of athletes in training. FIU-HCET will improve a system that implements biotelemetry with the following vital sign monitoring: skin temperature, Electro Cardio Gram (ECG), dehydration sensing, blood pressure. All of these are indicators of an approaching heat stress condition.

This data will be collected and tracked by computer. The computer will transmit an alarm to the worker if vital signs exceed allowable minimum safety limits (AmSL) for the onset of heat stress. Worker health and safety benefits from a reduction in heat stress injury. Production benefits from a non-injured workforce that is optimally efficient.

3.0 TECHNOLOGY DESIGN AND APPARATUS

The figure below shows the functional partition of the PMH. Standard sensory input consists of analog voltage waveforms that, for example, vary in magnitude with heart rate. A condition module that filters the transient components out of the waveform receives these analog signals. This process is also known as noise reduction. An Analog-to-Digital Converter (ADC) unit translates the waveform into a digital stream representing the magnitude of the analog signal at a given instant in time. Each sensor's waveform to this point is traveling along a separate channel or path. The multiplexer combines each channel into a single channel that the transceiver transmits to a monitoring computer. If an alarm is received by the PMH, a vibration alarm is activated similar to those used in personal pagers. The worker can then remove himself to a recovery area.

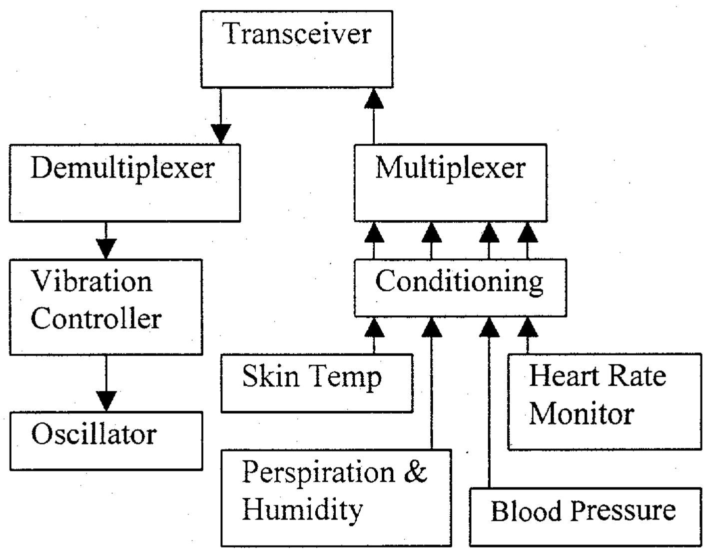

Figure 1. PHM operational unit diagram.

4.0 CONCLUSION AND RECOMMENDATIONS

The Personal Ice Cooling System (PICS) by Delta Temax performed better than other PCS evaluated in this study. The system requires no doffing to recharge the cooling media. Assistance is required for donning the belt-mounted unit and changing out the ice bottle. Project management at Fernald believe the on-site test of the PICS to be a success and are promoting the use of the device. Though PICS is not presently a PPE mandate, a number of units have been bought and are being used at Fernald.

With certain improvements, Kool N' Safe's KoolJacket Lite™ shows the most promise. It is the least expensive technology. Vests are not as bulky as other PCS. Recharge of PCM packs requires low cost and readily available tap water and ice. The limitation of doffing PPE to recharge the PCM packs would be offset if stay time and worker efficiency were improved. FIU-HCET can recommend both or similar technologies to meet DOE heat stress strategy needs.

5.0 REFERENCES

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Kalavapudi, M. 1994. *Topical Report Personnel Protective Clothing Needs Within the DOE Weapons Complex*, Energetics.

1995. *Carolina's Medical Center Biotelemetry Project Year-End Report*, The University of North Carolina at Charlotte.

Rezendes, V. 1993. *Worker Safety and Health Oversight Issues Facing DOE*, United States General Accounting Office.

APPENDIX A

COOLING PPE VENDORS

COOLING PPE VENDORS

Cooling PPE Vendor Information	
Aerospace Design and Development, Inc. 4699 Nautilus Crt South, Suite 205 Boulder, Colorado 80301 Phone: (303) 530-2888 Fax: (303) 530-2886 Email: addbldr@tesser.com	Delta Temax, Inc 320 Boundary Road Pembroke, Ontario K8A 6W5 Canada Phone: (613) 735-3996 Fax: (613) 735-3814 Email: deltatmx@webhart.net
Kappler N.A. P.O. Box 218 Guntersville, AL 35976 Phone: (800) 633-2410 Phone: (256) 505-4000 Fax: (256) 582-2706 Email: info@kappler.com	Kool N' Safe Co., Inc. 5114 11th Ave Brooklyn, NY 11219 Phone: (718) 853-8167 Fax: (718) 243-1070 Email: Jkool5114@aol.com
MicroClimate Systems, Inc. 965 E. Saginaw Rd Sanford, MI 48657 Phone: (800) 397-3004 Fax: (201) 818-1708 Email: info@micoclimate.com	Texan Corporation 205 Witmer Rd Horsham, PA 19044-2212 Phone: (800) 255-6960 Phone: (215) 441-8967 Fax: (215) 674-3922

APPENDIX B

BIOTELEMETRY VENDORS

BIOTELEMETRY VENDORS

Biotelemetry Vendor Information	
Mini-Mitter Co., Inc. P.O. Box 3386 Sunriver, Or 97707 Phone: (541) 593-8639 Fax: (541) 593-5604 Email: mm@minimitter.com	UNCC DECE 340 Smith Building 9201 Univ. City Blvd Charlotte, NC 28223 Phone: (704) 547-4391 Fax: (704) 547-2352 Email: tpweldon@uncc.edu

APPENDIX C

PPE VENDORS

PPE Vendor Information	
Accurate Safety Distributors, Inc. Freeland, MI 48623 USA Phone: (517) 695-6446 Fax: (517) 695-2543	Allegro Industries Garden Grove, CA 92641USA Phone: (800) 923-3066 Fax: (562) 633-2224
Anesthesia Associates, Inc. 460 Enterprise Street San Marcos, CA 92069 USA Phone: (760) 744-6561 or (619) 644-6561 Fax: (800) 883-9687	Arbill Philadelphia, PA 19132 USA Phone: (800) 664-9861 Fax: (760) 744-0054
Bird Barrier America, Inc. 1312 Kingsdale Avenue Redondo Beach, California 90278, USA Phone: (310) 793-1733 or (800) 503-5444 Fax: (310) 793-1732	Company Paasche Airbrush Equipment Paasche, 7440 W Lawrence Ave. Harwood Heights, IL 60656-3412 USA Phone: (708) 867-9191 Fax: (708) 867-9198
Conney Safety Products Co. Madison, WI 53744 USA Phone: (800) 532-1856 Fax: (800) 845-9095 or (608) 271-3322	Dantack Corporation 2521 Dalworth St. Grand Prairie, TX. 75050 Phone: (214) 988-8200 or (800) 272-6887 Fax: (214) 606-1600 E-mail: dantack1@airmail.net
Dietz Co., Inc., The Henry G Long Island City, NY 11102 US Phone: (888) 866-5641 Fax: (718) 728-3976	Eastco Industrial Safety Corp. Huntington Station, NY 11746 USA Phone: (800) 411-7307 Fax: (516) 427-1840
*ENMET Corporation PO Box 979 Ann Arbor, MI 48106 Phone: (313) 761-1270 Fax: (313) 761-3220 E-mail: info@enmet.com	Environmental Engineering Lab. 3538 Hancock San Diego, CA Phone: (619) 298-6131

PPE Vendor Information	
Gempler's Direct AG Supply Specialists Gempler's, 211 S Blue Mounds Rd. PO Box 270, Mount Horeb, WI 53572 USA Phone: (800) 382-8473 or (608) 437-4883 Fax: (800) 551-1128	Georgia Steel & Chemical Co. Inc. 10810 Guilford Road Annapolis Junction, MD 20701 Phone: (301) 317-5502 or (800) 296-0351 Fax: (301) 470-6313
Gerson, Louis M., Co., Inc. 15 Sproat Street Middleboro, MA 02346 USA Phone: (888) 679-4400 or (508) 947-4000 Phone: (800) 225-8623 Fax: (800) 4-GERSON or (508) 947-5442	Hambros Wire Rope, Inc. 2130 W. 15th Street Long Beach, CA Phone: (800) 281-8883
Industrial Safety & Security Co. Lima, OH 45801 USA Phone: (419) 227-6030 Fax: (419) 228-5034	Interspiro Branford, CT 06405 USA Phone: (203) 481-3899 Fax: (203) 483-1879
Lyons Safety Germantown, WI 53022 USA Phone: (414) 255-7300 Fax: (414) 255-7307	Marquest Medical Products, Inc 11039 E. Lansing Circle Englewood, CO. 80112 Phone: (303) 790-4835 Fax: (303) 799-0210
Martech Services Co. Rochester, MN 55903 USA Phone: (800) 831-1525 Fax: 507-843-4953	Mercer Products Div., Boig & Hill, Inc. Valley Stream, NY 11580 USA Phone: (800) 800-7228 Fax: (516) 561-1107
Modern Industrial Supply Co. 9840 Indiana Avenue Riverside, CA Phone: (800) 486-4568	Moldex / Metric, Inc. 4671 Leahy Street Culver City, CA Phone: (310) 837-6500

PPE Vendor Information	
*MSA Pittsburgh, PA 15230-0426 USA Phone: (888) 867-0604 Fax: (412) 967-3450	*MSC Industrial Supply Co. Plain view, NY 11803 USA Phone: (800) 753-7937 Fax: (516) 349-0265 Overseas: (800) 255-5067
National Draeger, Inc. P. O. Box 12 Pittsburgh, PA 15230-0120 Phone: (412) 787-8383 or (800) 922-5518 Fax: (412) 787-2207 E-mail: prodinfo@national.draeger.com	Neoterik Health Technologies, Inc. 401 Main St. Woodsboro, MD 21798 Phone: (301) 845-2777 Fax: (301) 845-2213
Newark Safety Equipment Co. Newark, NJ 07105 USA Phone: (973) 344-1051 Fax: (973) 344-6592	North Safety Product Cranston, RI 02920 USA Phone: (401) 943-4400 Fax: (401) 942-9360
Pro-Tech Respirators, Inc. Smithfield, RI 02917 USA Phone: (401) 232-1200 FAX: 401-232-1830	Puritan Bennett Corp. Of California 3310 Camino Vida Roble Carlsbad, CA Phone: (619) 929-4000
Racal Health & Safety, Inc. Frederick, MD 21701-8354 USA Phone: (301) 695-8200 Fax: (301) 695-4413	Resna 17062 Murphy Avenue Irvine, CA Phone: (714) 756-8666
Respiratory Systems, Inc. 16912 A Von Karman Avenue Irvine, CA Phone: (714) 250-9000	Rhine Air, Inc. 10744 Prospect Avenue Santee, CA Phone: (619) 460-5928

PPE Vendor Information	
SAS Safety Corp. Signal Hill, CA 90806 USA Phone: (800) 262-0200 Fax: (800) 244-1938	Scott Aviation, A Div. of Figgie International Inc. Monroe, NC 28112 USA Phone: (704) 282-8400 Fax: (704) 282-8400
Survivair 3001 S. Susan Street Santa Ana, CA Phone: (714) 850-0299	Uvex Safety Inc., A Bacou<TM> USA Co. Smithfield, RI 02917-1896 USA Phone: (800) 232-2623 Fax: (401) 232-1830
Wallace Industries PO Box 1281 Port Lavaca, Texas 77979 Phone: (512) 552-7882	Willson Safety Reading, PA 19603 USA Phone: (610) 376-6161 Fax: (610) 371-7725
Zee Medical, Inc. 22 Corporate Park Irvine, CA (800) 228-2878	

APPENDIX D

KOOLJACKET LITE™ (KV-4-65) SPECIFICATIONS

KOOLJACKET LITE™ (KV-4-65) SPECIFICATIONS

KoolJacket Lite™ (KV-4-65)

Mid-size of the PCM™ cooling vests. Feature one-time multiple adjustments and an easy on/off front zipper. Not as heavy as the KoolJacket™, and easier to get on and off than the KoolVest™. Complete with 1-piece fabric carrier, 4 standard vest size KoolPacks™ containing 65 degree PCM™ and 6 adjustable straps.

Total weight = 4.8 pounds

Carrier Length = 25 inches (From top of shoulder to bottom of carrier)

Carrier Width = 16.5 inches (front) and 13.25 inches (back) (Does not include adjustable waist strap length)

Carrier Fabrics and colors available = Supplex/White, Banox FR3/Blue

KoolPack Weight (each) = 400 Grams of 65 degree PCM

KoolPack Weight (total) = 1600 Grams of 65 degree PCM

Square inches of cooling per KoolPack = 54

Square inches of cooling total = 216

KoolPack shell material = 100% virgin polyurethane (10 mil)

Typical cooling duration* = 2 to 2.5 hours @ 100° F

Typical recharge Time** = 20 minutes in container of ice and water

* These durations may vary based on the wearer's physiology, workload, and the multiple variables associated with the work environment.

** Recharging can also be accomplished via a refrigerator or freezer. These times vary due to KoolPack placement and temperature settings. These times are usually around an hour.

KoolJacket Lite Sizing Chart

KJL-SM = Men's Chest sizes less than 36"

KJL-ML = Men's Chest sizes 36" to 48"

KJL-EL = Men's Chest sizes 50" to 60"